Final Report: Microbeam Investigations of Presolar and Early Solar System Materials.
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This grant provided three years of funding for my Cosmochemistry research program at Arizona State University. This research resulted in 11 peer-reviewed papers in six Journals and 35 abstracts to 11 Conferences and Workshops (see list below). My original proposal listed three main areas of research: 1) Studies of presolar grains; 2) Studies of short-lived radionuclides and; 3) Investigations of nebular processes and the origin of chondritic component.

The main results in the study of presolar grains were:

1) With Post Doc Julie Smith, I continued to work on characterizing the isotopic compositions of presolar SiC grains. One important result was the detailed measurement of Ti isotopes in Orgueil SiC grains that had previously been measured for Si, C, N, and Mg isotopes (Smith and Huss, 2002). These data are being written up for publication in Atrophysical Journal. The other major result was the discovery that N isotopic compositions in SiC grains may correlate with the pre-accretionary history of the host meteorite (Smith and Huss, 2003; Smith et al., 2004). This work is ongoing.

2) I presented an invited review paper at the NIPR symposium on Anarctic meteorites in 2003 based on my work on presolar grains, their abundances, the characteristics of the matrix of primitive meteorites, and the bulk chemical characteristics of primitive meteorites. In this review, which was published as Huss (2004), I discussed evidence that the chemical compositions of the chondrite groups were produced by the same processes that affected the abundances and characteristics of presolar grains in the unmetamorphosed members of each class. The observed correlations between these two data sets effectively preclude nebula-scale evaporation and condensation as the mechanism of chemical fractionations among meteorite classes. The only way that presolar grains could have survived is if the processing involved differential heating of the basic presolar dust inherited from the sun's parent molecular cloud.

The main results in the study of short-lived radionuclides were:

1) We completed and published our collaborative study of ^{10}Be in type A CAIs from CV chondrites (MacPherson et al., 2003). We showed that these inclusions all acquired ^{10}Be from the nebula in abundances similar to those in type B CAIs. We also showed that ^{10}Be and ^{26}Al initial abundances are not correlated in these objects (ours was actually the first work to show this, but because we did not publish in Nature, our work was not the first published).

2) We discovered the first clear evidence for ^{60}Fe in chondritic materials. My Post Doc, Shogo Tachibana, found this evidence in troilites from the Bishunpur and Krymka meteorites (Tachibana and Huss, 2003). Once this discovery was announced, the Mainz group quickly found similar evidence in troilites from Semarkona, and our group in collaboration with Yunbin Guan of ASU found evidence for ^{60}Fe in E chondrite sulfides (Guan et al., 2003, 2004). This last work showed that sulfides are very susceptible to metamorphism, so we decided that we must find evidence of ^{60}Fe in a mineral that records the initial ratio with more fidelity. We succeeded in finding this evidence in a pyroxene-bearing chondrule from Semarkona (Huss and Tachibana, 2004 abst). This work is continuing under our new Cosmochemistry funding and new results were presented at LPSC XXXVI (Tachibana et al., 2005).

The main results in investigations of nebular processes and the origin of chondritic components were:

1) Glenn MacPherson and I finished our paper on the origina of Al-rich chondrules in ordinary chondrites (MacPherson and Huss, 2005, in press in GCA). In this paper, we showed that the mineralogy and mineral chemistry of the majority of Al-rich chondrules are governed by the bulk compositions of the chondrules—i.e., they do not contain relict phases. We also showed that the diversity of mineralogies can be predicted from a Cosmochemical Phase diagram that we produced for that purpose. We also show that Al-rich chondrules are intermediate, in a volatility sense, between CAIs and ferromagnesian chondrules.

2) With Shogo Tachibana, I studied mass fractionation in supposed primitive troilites inside chondrules of Semarkona and Bishunpur. We found that the sulfur is not mass fractionated, as might be expected from evaporative loss to space. Because it seems clear that sulfur was lost from chondrules during melting, we investigate a number of scenarios that might explain the lack of isotope fractionation. An important conclusion of our work is that chondrule heating times must have been very short in order to preclude mass fractionation of sulfur during heating (Tachibana and Huss, 2005, in press in GCA).

3) Ryuji Okazaki and I studies oxygen isotopes in chondrules from enstatite chondrites. The motivation was to understand the presence of primitive noble gas components in these chondrules. We had to do a lot of work to improve the precision of oxygen isotopic analysis by ion microprobe. We developed a better data-reduction scheme and learned how to handle correlated errors. We also learned to use a new Z-stage that was installed on the 6f, which reduced the uncertainties in instrumental mass fractionation effects by a factor of several. Preliminary results of this work were presented in Okazaki and Huss (2003a, b, c abstracts).

4) As part of a collaborative study with Sasha Krot and Ian Hutcheon, I measured oxygen isotopic compositions of CAIs and other interesting includions in Adelaide (Huss et al., 2003 abstract). These data confirm that Adelaide is one of the most unmetamorphosed chondrites.

5) In collaboration with Xin Hua at ASU, I studies Si, O, and Mn-Cr isotopes in fayalites from the Kaba CV3 chondrite. One motivation for this study was a report of extreme mass fractionation effects in Kaba fayalites at the Chicago Metsoc meeting. We were unable to confirm the previously reported effects, but we were able to provide important constraints on the timing and formation mechanism of Kaba fayalites (Hua et al., 2005 GCA).

"Target-of-opportunity" studies:

1) In collaboration with Ronit Kessel, John Beckett, and Ed Stolper, I carried out careful ion probe measurements of the Cr content in spinels and surrounding phases in equilibrated ordinary chondrites. The Cr concentration is a good indicator of oxygen fugacity in these meteorites. These results were the first reliable measurements of Cr in the metal phase surrounding the chromites. These data constrain the fO2 for equilibrated H chondrites to be 2.19-2.56 log units below IW for the temperature range of 740 to 990 C (Kessell et al., 2004 MAPS).

2) With Thorbjoern Schoenbeck, I carried out measurements of the Si concentrations in Fe-Ni metal from CB and CR chondrites. These metal grains have trace-element profiles that indicate direct concensation from the gas phase, and the Si concentration helps to constrain the fO2 of condensation. These data indicate that the conditions where the zoned metal grains formed were more oxidizing that the canonical solar nebula. These results were presented at the XXXVI (Schoenbeck et al., 2005).

All of these results have had a significant impact on research in Cosmochemstry. As you will also see from the publication list, several other studies were started or finished during the grant period.

Major equipment grant: An equipment grant was awarded in connection with my Cosmochemistry research grant. This grant provided money for a secondary electron and precision stage positioning system for the ASU ion microprobe and an upgraded stage positioning system for the supporting scanning electron microscope. The secondary electron detector was installed in early 2004 and was very useful in measurements of nitrogen isotopes in SiC grains and in investigating ways to measure grains in aerogel. As it turned out, by the time the money became available, Cameca no longer manufactured the secondary electron detector, so they had to find a used one to sell to us. This actually saved us quite a bit of money and with these savings, we purchased an Keithley electrometer to upgrade the Faraday cup electronics and a Phillips amplifier and discriminator to improve the performance of the electron multiplier. The stage positioning systems were acquired in late 2004 and early 2005 and are awaiting installation on their respective machines.

Papers resulting from research supported by this grant:

Takeda H., W. Hsu and G. R. Huss (2003) Mineralogy of silicate inclusions of the Colomera IIE iron and crystallization of Cr-diopside and alkali feldspar from a Partial melt. *Geochim. Cosmochim. Acta* **67**, 2269-2288.

MacPherson G. J., G. R. Huss and A. M. Davis (2003) Extinct ^{10}Be in Type A CAIs from CV chondrites. *Geochim. Cosmochim. Acta* **67**, 3165-3179.

Hsu W., G. R. Huss and G. J. Wasserburg (2003) Al-Mg systematics of CAIs, POI, and ferromagnesian chondrules from Ningqiang. *Meteorit. Planet. Sci.* **38**, 35-48.

Tachibana S. and G. R. Huss (2003) The initial abundance of ^{60}Fe in the solar system. *Astrophys. J.* **588**, L41-L44.

Guan Y., G. R. Huss, and L. A. Leshin (2004) SIMS Analyses of Mg, Cr, and Ni Isotopes in Primitive Meteorites and Short-lived Radionuclides in the Early Solar System. *Applied Surface Science* **231-232**, 899-902.

Kessel R., J. R. Beckett, G. R. Huss and E. M. Stolper (2004) The activity of chromite in multicomponent spinels: Implications for the redox conditions of equilibrated H chondrites. *Meteorit. Planet. Sci.*, **39**, 1287-1305.

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Tachibana S. and G. R. Huss (2005) Sulfur isotope composition of putative primary troilite in chondrules from Bishunpur and Semarkona. Geochim. Cosmochim. Acta, in press.

Abstracts resulting from research supported by this grant:

Hua X., G. R. Huss and T. G. Sharp (2002) ^{53}Mn-^{53}Cr dating of fayalite formation in the Kaba CV3 carbonaceous chondrite. *Lunar Planet. Sci.* **XXXIII**, #1660.

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Tachibana S. and G. R. Huss (2002) Sulfur isotope composition of putative primary troilite in chondrules. *Lunar Planet. Sci.* **XXXIII**, #1685.

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Guan Y., G. R. Huss, G. J. MacPherson and L. A. Leshin (2002) Rare earth elements of calcium-aluminum-rich inclusions in unequilibrated enstatite chondrites: characteristics and implications. *Meteorit. Planet. Sci.* **37**, A59.

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Huss G. R., I. D. Hutcheon, A. N. Krot and S. Tachibana (2003) Oxygen isotopes in refractory inclusions from the Adelaide carbonaceous chondrite. *Lunar. Planet. Sci.* **XXXIV**, #1802.

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Huss G. R. (2003) Implications of presolar grains and isotopic anomalies for solar system formation. Invited presentation to the NIPR International Symposium, "Evolution of solar system materials: A new perspective from Antarctic Meteorites, 40-41.

Guan Y., G. R. Huss, and L. A. Leshin (2003) ^{60}Fe, ^{53}Mn, and nickel isotope anomalies in sulfides from enstatite chondrites. Presented at the NIPR International Symposium,

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